

**DRAFT**

**Bering Sea Ecosystem Research Plan**

**April 24, 1998**

## **Preface**

On December 4 and 5, 1997, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Interior (USDOI), and the Alaska Department of Fish and Game (ADF&G) sponsored a Bering Sea Ecosystem Workshop in Anchorage, Alaska. The purpose of the workshop was to promote research coordination and data sharing among organizations that study, manage, and utilize resources of the Bering Sea. One of the recommendations of the workshop led to the development of an integrated Bering Sea ecosystem research plan.

This is a draft of the research plan written under NOAA's direction by scientists from NOAA, the USDOI, and ADF&G. This draft is being distributed for broader review and consideration by other groups involved in the Bering Sea.

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## **Bering Sea Ecosystem Research Plan**

### **Vision of the Bering Sea**

*We envision a productive, ecologically diverse Bering Sea ecosystem that will provide long-term, sustained benefits to local communities and the nation.*

The Bering Sea is the most productive marine ecosystem off the coast of the United States and one of the most productive in the world. Over the last few years observed changes elicit our concern for the health of the ecosystem and help shape our vision for its future. Attaining our vision requires incorporation of traditional knowledge and implementation of coordinated research to improve our understanding of how this extraordinary ecosystem functions and how to manage it wisely. Coordinated research must focus on vital management issues that affect the ecosystem and provide methods to improve prediction of ecosystem production and maintenance of ecosystem health and stability. Key aspects of implementing this research are sustained support, coordination, communication, and involvement of local communities and stakeholders. Finally, we must translate traditional knowledge and scientific understanding into dynamic management policies that promote optimal consumptive and non-consumptive uses of present Bering Sea resources, anticipate changes in resource abundance and distribution, and ultimately reduce the uncertainty in the decisions that we make regarding use of marine biological resources and their environment.

### **Introduction**

The Bering Sea is one of our nation's richest marine resources. In the last few years, at least ten agencies and institutions have expressed concerns about environmental changes being observed in the Bering Sea and have developed science plans addressing aspects of the ecosystem. Many of these agencies participated in a Bering Sea Ecosystem Workshop held in Anchorage, Alaska, on December 4th and 5th, 1997. One of the recommendations from this workshop is to develop an integrated Bering Sea Ecosystem Science Plan and this is the primary purpose of this document. Coincidentally, Congress created an Environmental Improvement and Restoration Fund to be administered by a North Pacific Research Board to "conduct research activities on or relating to the fisheries or marine ecosystems in the North Pacific Ocean, Bering Sea, and Arctic Ocean (including any lesser related bodies of water)." It is hoped that this draft Bering Sea Research and Implementation Plan might serve the North Pacific Research Board (NPRB) in guiding needed research in the Bering Sea. Later, similar science plans will need to be developed for the North Pacific Ocean and Arctic Ocean.

Rather than duplicating previous efforts, our intent is to integrate the recommendations of all concerned programs and institutions and synthesize recent research plans and recommendations (Appendix) developed by the National Research Council (NRC); Bering Sea Impacts Study (BESIS); Arctic Monitoring and Assessment Program (AMAP); Global Ecosystems Dynamics (GLOBEC); North Pacific Marine Science Organization (PICES); and the National Oceanic and Atmospheric Administration (NOAA) through the Arctic Research Initiative (ARI), Fisheries-Oceanography Coordinated Investigations (FOCI), Coastal Ocean Program's Bering Sea FOCI and Southeast Bering Sea Carrying Capacity (SEBSCC), and the Marine Mammals Protection Act (MMPA) Bering Sea Ecosystem Study. In addition to these research plans specific to the Bering Sea, a number of other planning efforts have resulted in research plans for marine

resources off the coast of Alaska. Such relevant efforts include: (1) Alaska Regional Marine Research Board's Alaska Research Plan (ARMRP 1993), (2) Minerals Management Service's Alaska Environmental Studies Strategic Plan, FY 1999-2000 (MMS 1997), (3) future research needs for North Pacific flatfish (Smith 1995), (4) crab research needs identified at an international crab symposium (Paul 1996), (5) an interagency long-term plan for crab research (Kruse 1996), (6) future research needs for rockfish (Clasby 1987), and (7) research needs on forage fishes (Hay 1997). We feel that a sound, integrated Bering Sea Ecosystem Research Plan can be developed by synthesizing these accumulated research recommendations, recognizing those needs that have been addressed by recent and ongoing programs, and identifying remaining gaps in knowledge.

## **Background**

### *Description of the Bering Sea*

The Bering Sea, a northern extension of the North Pacific Ocean, is the world's third-largest semi-enclosed sea. Its wide eastern shelf makes up about half its total area. The Bering Sea is home to a rich variety of biological resources, including the world's most extensive eelgrass beds; at least 450 species of fish, crustaceans, and mollusks; 50 species of seabirds; and 25 species of marine mammals. The abundant fish and wildlife of the Bering Sea have supported the lives and livelihoods of Asians and North Americans since prehistoric times. Presently, the U.S. Bering Sea fishery provides about 40% of the U.S. and about 5% of the world harvest of fish and shellfish; walleye pollock comprise much the fish landings, Bristol Bay supports the world's largest sockeye salmon fishery, and the snow crab fishery is currently the largest crustacean (by weight) fishery in the U.S. In addition to supporting a large portion of the nation's fishery production, the Bering Sea also supports 80% of the U.S. seabird population comprising 36 million birds of 35 species. Furthermore, many unique and endemic species such as red-legged kittiwakes and whiskered auklets are found in the Bering Sea and further highlight the significance of this region. A variety of recent agreements designed to protect marine mammals, birds, and fish resources have been adopted by the United States, other nations, and international organizations interested in the Bering Sea. Despite these agreements, some species of the Bering Sea and adjacent regions have undergone large and sometimes sudden population fluctuations.

The Bering Sea is always changing. Large-impact, easily documented perturbations recently occurred that can be attributed to climate fluctuations or human impact on the ecosystem. The relatively warm and calm summer of 1997, for example, brought a rare bloom of coccolithophores, a phytoplankter more typical of nutrient-limited subtropical waters, a massive die-off of marine birds, and a commercial fishery failure in Bristol Bay salmon. Human-induced change in consort with climate change is a premise of the Cascade Hypothesis proposed by the National Research Council in 1996. The hypothesis relates declines in sea bird, sea lion, and seal abundances during the last two decades to substantial removals of fish and whales from the mid-1950s to the early 1970s and pollock-favorable environmental conditions associated with a decadal regime shift in the late 1970s.

### *Brief history of ecosystem research*

Much of the early ecosystem research in the eastern Bering Sea was conducted to address questions related to the international fishery. Between the mid-1970s and late 1980s, additional

issues became important. There were resource assessments over much of the eastern shelf as part of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), ecosystem research over the southeastern (Processes and Resources of the Bering Sea -- PROBES) and northern (Inner Shelf Transfer and Recycling in the Bering and Chukchi Seas -- ISHTAR) shelf, and examination of ice related phenomenon (Bering Sea Marginal Ice Zone Experiment -- BS MIZEX).

In the 1990s, the Bering Sea ecosystem received even more attention, due in part to the collapse of the U.S. fishery on the New England continental shelf. The scope of research has broadened to consider the ecosystem in its entirety, with a focus on integrated, multidisciplinary studies that include studies of ocean processes to ecosystem interactions (e.g., Southeast Bering Sea Carrying Capacity—SEBSCC, Arctic Research Initiative --ARI, and Seabird, Marine Mammal and Oceanography Coordinated Investigations—SMMOCI). Summaries of recent programs, their histories, and scientific issues are presented in the appendix of this document.

### **Fishery and ecosystem management issues and concerns**

Not all previous Bering Sea scientific plans have explicitly outlined the key management issues that drive the need for research. However, there are presently many management issues that require a focused research program, particularly issues that are linked to concerns about the ecosystem. Some management issues are particularly acute because they require immediate action in the face of uncertain scientific knowledge. Other issues require a long-term commitment to research.

The most pressing management issues concern the possible effects of humans on the ecosystem. Perhaps the greatest concerns involve the potential effects of fishing on benthic communities and habitats, and on endangered or threatened marine mammals, and seabirds. Unfortunately, the nature and extent of fishing effects are unknown. Specific concerns include localized depletions of prey in important mammal foraging areas, effects of fishing on attached invertebrates and bottom habitat structures that may provide important food and cover for some species, effects of discards on benthic predator-prey dynamics, potential effects of removal of carbon on long-term productivity of the system, and possible effects of truncated size structure on predator-prey dynamics and on a fished population's ability to withstand periods of poor recruitment. Other concerns from human activity include effects of large-scale salmon enhancements, coastal development in sensitive shallow-water nursery areas, introduction of exotic species via ballast water or live tanks, and introduction of contaminants, plastics, and other materials into the environment. Subsistence users of Bering Sea resources require sufficient resource levels to sustain their harvest. They also require information about contaminant levels in subsistence resources to make appropriate choices about consumption.

Despite the scarcity of scientific studies on these areas of concern, fisheries have been restricted in many areas and at certain times of year to mitigate possible effects of fishing on other ecosystem components. Examples include closures due to concerns about benthic habitat in areas important to red king crab and concerns about forage species near sea lion rookeries. However, these restrictions were made with little information to guide managers. It is not known whether these actions are having the desired effect or whether different measures might be more effective. Regardless, these restrictions have had negative effects on some commercial fisheries,

and so there are costs associated with lack of information. Directed research on the effects of fishing on the ecosystem is required to help fisheries managers make better informed decisions.

Other issues facing fishery and wildlife managers are those that relate to ensuring the long-term productivity of the resources. Decadal scale climate shifts have been linked to changes in ocean productivity and shifts in species available for harvest. Improved understanding of climate and its effects on living marine resources will assist in developing management strategies that can accommodate to changes in production and ease economic dislocations that might result from such changes. Management strategies are needed that are not solely based on steady-state models of fish production, but which also incorporate climate-induced variability in fish production. In addition, climate factors may shift the distribution and abundance of key resources such as pollock to areas outside the eastern Bering Sea where they might be exposed to a less conservative management regime. A program that focuses on understanding the effects of climate change on resource production will help us design better management strategies.

Additionally, the build-up of contaminants poses a potential threat to marine populations and to sustainable subsistence and commercial use of living marine resources of the Bering Sea. An understanding and prediction of the trends in contaminants levels, especially as these relate to long-range transport from other more polluted regions, is needed to assure the maintenance of a healthy and productive Bering Sea ecosystem.

### **Scientific issues**

Many of the variations in the Bering Sea ecosystem are physically forced by climate variability. These variations include storm tracks and storm intensity that change vertical mixing and sea ice, cloud cover, thermohaline circulation, ocean currents and water mass exchange with adjacent oceans, and nutrient concentrations. Climate forcing of these oceanographic features affect the productivity and species composition of lower trophic levels which provide food for other components of the ecosystem. The distribution and abundance of upper trophic level species in the Bering Sea can be influenced by climate variability either directly or indirectly. Direct effects may be alteration of physical habitat (temperature, mixed layer depth, or bottom disturbance) and implications on growth, mortality, and reproductive success. Indirect effects may be bottom up (effects of changes at lower trophic levels) or top down (effects of predator abundance or distribution).

The combined effects of variability in physical forcing, the structure and function of food webs, commercial harvest levels, and other anthropogenic disturbances can cause changes in the Bering Sea ecosystem. Alterations in either physical forcing, or commercial harvest practices may force the ecosystem into a new state, in which a new set of species dominate. Understanding the complex biophysical system interactions, including direct and indirect effects of fishery removals, that structure the Bering Sea ecosystem is critical to determining and monitoring its health. With this knowledge, not only can human-induced changes be mitigated, but management strategies can be designed that incorporate natural variability.

## **Overarching hypotheses**

The synthesis of previous programs suggests a pair of hypotheses that span current management and science issues.

1. Climate changes at decadal scales and at global scales, teleconnected to the Bering Sea by the atmosphere-ocean-ice system, cause shifts in dominant marine species and alter the overall productivity of the Bering Sea.
2. Human impact leads to environmental degradation, including increased levels of contaminants, loss of habitats, and increased mortality on certain species in the ecosystem that may trigger changes in species composition and abundance.

## **Research themes and approaches**

These overarching hypotheses suggest several research themes, associated scientific questions, and approaches for answering the questions. Recommended research addresses ecosystem understanding and management, and recognizes the long-term, critical science questions that will remain when currently funded programs are completed. Research themes are climate variability, ocean processes, individual species responses, food web dynamics, contaminants and other introductions, and habitat.

### *Climate variability*

Natural climate variability influences the Bering Sea on a range of time scales, from annual to decadal and longer periods. Natural climate cycles can be influenced by anthropogenic effects, and anthropogenic variations are often masked by natural fluctuations. The decadal scale is a dominant mode of observed climate variability for the Bering Sea, and it has the greatest impact on management concerns about sustaining productivity. Climate change on the decade scale originates primarily in the atmosphere and spans the North Pacific Ocean, northeastern Asia and the western Arctic. It is unclear how much decadal variability is generated in the atmosphere and how much is forced through feedback with sea ice extent, snow cover and sea surface temperature. Major changes have occurred over the decades, often alternating between warm and cold periods or regimes.

A major recent change occurred in 1977 when the Bering Sea went from a cold regime to a warm regime; this change was primarily due to an intensification of the Aleutian Low over the North Pacific Ocean. A second change occurred in 1990, related to changes in the western Arctic and northeastern Asia, that suggests present tendencies are for a colder Bering Sea regime in winter and a warmer regime in spring and summer. While decadal variability in the North Pacific can be traced back to the turn of the century, the Arctic influence does not appear before 1970 and is primarily evident in the 1990s. Global warming occurs on longer time scales, and its effects may be superimposed on decadal and annual changes. Understanding existing and emerging climate patterns are necessary to understand and perhaps predict impacts of climate change on the ecosystem.

Questions: What are the mechanisms that determine the climate of the Bering Sea, particularly at the decadal scale? What triggers the formation and strength of El Niño-Southern Oscillation events and the position and intensity of the Aleutian Low? What causes natural cycles? How do



atmospheric and oceanographic features interact to affect one another ? How is climatology of the Bering Sea linked to the Gulf of Alaska? How can we identify anthropogenic effects?

Possible approaches: Statistical analysis of time series data can identify climate variability on intraseasonal, interannual, and decadal and longer scales. Routinely collected data are likely sufficient for analysis, so modeling is a primary means of understanding the processes and interactions of variability in the coupled system.

#### *Ocean processes*

A number of ocean processes may be critical to the dynamics of the Bering Sea ecosystem. Ocean currents are driven by wind, tides, and the heat and salt balance in the ocean. The source waters for the Bering Sea flow through the Aleutian passes from the North Pacific Ocean and strongly influence circulation. For the eastern shelf, the Aleutian North Slope Current carries Alaskan Stream water eastward along the north side of the Aleutian Islands, forming the Bering Slope Current in the southeastern corner of the basin.

Exchange between the oceanic and shelf regimes is essential to provide nutrients to the shelf. As much as 50% of the annual nitrogen needed to support the high productivity on the shelf must be derived from outside sources such as nutrients present in the deep ocean. The processes which result in basin-shelf exchange include eddies, meanders and transport associated with topographic features. These processes are poorly understood and their link to changes in atmospheric forcing and North Pacific circulation is also uncertain. Net northward transport through Bering Strait requires an onshelf flux of nutrient rich water onto the eastern Bering Sea shelf. Transport through Bering Strait, driven by sea level differences between the North Pacific and Arctic Oceans, will decrease if the Arctic warms to a greater extent than the North Pacific. How this will impact the flux of nutrient rich water onto the eastern shelf is not known, however there is some evidence from carbon isotope data that productivity of the Bering Sea has been declining since the mid-1960s (Schell 1997).

Seasonal sea ice extent fluctuates over 1000 km from north of Bering Strait in summer to the Alaska Peninsula and eastern Bering Sea shelf break in winter. The amount of production and advection of ice depends upon storm tracks, with greatest ice production occurring in years when the Aleutian Low is well developed and winds from the north are common. Large variations (100s of km) occur in maximal sea ice extent. Other characteristics (e.g., duration of ice at its southern extent, time of retreat from the southernmost extent, and number of weeks that ice remains over the middle shelf) also vary greatly. Ice melt plays a critical role in heat and salt fluxes, generation of both baroclinic flow and structure, and the extent of cold bottom water located over the middle shelf. As seasonal heating occurs, the lower layer becomes insulated and temperatures often remain below 2.0 °C. It is these waters that are commonly called the "cold pool" whose area varies by about 200,000 km<sup>2</sup> between maximum and minimum extent. The cold pool has a dramatic influence on the distribution, and possibly on the production, of higher trophic level biota. Over the shelf the spring bloom of phytoplankton accounts for 10 to 65% of the total annual primary production. The presence of melting sea ice is associated with an early spring bloom. The reasons for this are not well understood, nor do we know the impact of an early spring bloom on energy transfer within the food web.

In addition to nutrient flux and sea ice dynamics, other oceanographic processes can be very important to the functioning of the Bering Sea ecosystem. It now appears that iron is a limiting element to primary production in many regions of the world's oceans. The source of iron in the Bering Sea is unknown. Iron may be supplied to the shelf from exchange with slope waters that form the "Green Belt" or it may be supplied by some other source. Also, processes that cause temporal and spatial variation in well mixed waters and stratified waters stimulate primary and secondary production.

On seasonal time scales, wind-driven mixing from winter storms brings nutrients into the euphotic zone, and stratification associated with warming of near-surface layers lead to a spring phytoplankton bloom followed by increased abundance of zooplankton consumers. Interannual variations in storminess and solar radiation affect mixing and stratification that regulate production. On spatial scales, ocean fronts are regions of juxtaposition between mixed waters and stratified waters of differing temperature, salinity, and nutrient concentrations. On continental shelves, fronts may be generated by tides, eddies, upwelling, and other mechanisms leading to regions of high productivity. On the eastern Bering Sea shelf, the PROBES program identified three domains separated by fronts (McRoy et al. 1986). The coastal domain, inshore of an inner front at 50 m depth, is comprised of a wind and tidally-driven mixture of coastal runoff and basin water. A middle domain, between the inner front and a middle front at 100 m, is a mixture of saline water and freshwater moving seaward. Unlike the inner domain, the middle domain becomes stratified into two water layers by seasonal heating. The lower layer is the coldest water on the shelf, and its temperature depends on severity of previous winter. Finally, an outer domain does not have an identifiable water mass, and it is bounded offshore by a shelf-break front at 200 m.

Processes regulating these fronts, their productivity, and their importance to a number of ecologically- and commercially-important species are not fully understood. Structures, such as eddies and fronts, may not only be important to primary production, but they may also be important sites for retention of eggs and larvae of fish and shellfish in areas of high prey abundance needed for survival. Ocean currents may also advect larvae from, for example, offshore spawning grounds to nearshore nursery areas important for survival of strong year classes.

Questions: How does climate variability influence circulation, stability of currents, sources and amounts of nutrients transported to the eastern Bering Sea shelf, and the resulting primary and secondary production regimes? What climatic and oceanographic conditions lead to the formation of fronts and eddies and what is their role in nutrient transport? Are interannual variations in mixed layer depth and onset of stratification associated with changes in primary and secondary production? How do these currents, eddies, and ocean fronts affect primary and secondary producers, fish and shellfish larval retention, survival, and year class formation? How does climate variability affect seasonal production and extent of sea ice? How does iron affect productivity of the Bering Sea, and what is the source of iron? How do changes in sea ice dynamics influence biophysical processes throughout the food web? Do changes in sea ice dynamics control the proportion of spring primary production available to pelagic and benthic communities?

Possible approaches: Conduct process-oriented studies and long-term monitoring of currents and water characteristics, and other features, nutrients, and primary and secondary production at key locations. Develop improved models of circulation and nutrient-phytoplankton-zooplankton

(NPZ) dynamics. Consider developing a program, analogous to one conducted in the North Atlantic Ocean since the 1940s (Colebrook 1986), in which a continuous plankton recorder could be towed behind merchant ships or other vessels on regular routes to monitor seasonal and interannual changes in the phytoplankton and zooplankton community across the basin, slope, and continental shelf in the Eastern Bering Sea. Conduct seasonal monitoring of physical water and ice characteristics, nutrients, primary and secondary productivity. Develop models of larval advection and retention for key species of fish and shellfish to identify climate features favorable to the formation of successful year classes.

#### *Individual species responses to perturbations*

Our understanding of status of the living marine resources in the Bering Sea ecosystem is largely confined to fish and invertebrates of commercial importance and mammals and birds readily observed from land or air. However, even this limited view of the ecosystem reveals that major changes have occurred among groundfishes, forage fishes, salmon, shellfish, marine mammals and seabirds. Many groundfish increased from the late 1970s through the 1980s. Most flatfish (e.g., yellowfin sole, rock sole, arrowtooth flounder) continued this increase to the early 1990s whereas walleye pollock and Pacific cod generally declined with the exception of an early 1990s increase of Pacific cod. A few groundfishes had very different trends: Greenland turbot have generally declined during this period and Pacific Ocean perch declined through the early 1980s followed by a modest increase.

Data on forage fishes is largely confined to Pacific herring which were at high abundance levels in the 1950s and 1960s and then declined with the exception of a temporary upswing increase from a strong 1977 and 1978 year classes and good survival.

Knowledge of invertebrates is largely restricted to crabs. Most crab stocks declined due to decreasing recruitment during the 1970s, but patterns in the 1980s and 1990s are species-specific. Bristol Bay red king crabs have continued at low abundances although a strong 1990 year class will result in partial stock rebuilding in the near future. On the contrary, red king crabs in Norton Sound have been stable with exceptions of a very strong year class in 1969 and very weak year classes in 1970, 1971, and 1985. Blue king and Tanner crab populations increased in the 1980s due to good recruitment, but since then blue king crabs at Pribilof Islands have declined, blue king crabs off St. Matthew Island remain abundant, and Tanner crabs have declined precipitously since peaking in 1990. Snow crabs experienced good recruitment in the mid-1970s and mid- to late 1980s, and abundance is expected to peak in the late 1990s prior to a sharp decline due to impending poor recruitment.

Salmon are also important members of the Bering Sea ecosystem during their marine life. During the 1980s and 1990s total salmon abundance has been very high, although specific runs, such as chinook and chum salmon in Western Alaska, have been poor.

Several marine mammal and seabird populations in the Bering Sea have declined precipitously. Steller sea lions and fur seals have declined sharply in the last few decades, and some significant declines have occurred in populations of sea birds, such as some murres, kittiwakes, and spectacled eiders.

The causes for these population changes are not well understood. Because declines of mammals and birds are most likely to be related to their prey, these declines are treated under the following research theme “Food web dynamics.” Regarding changes in fish and invertebrate, large shifts in species composition are probably triggered by direct climate effects on individual species through runs of strong year classes that sustains fisheries or runs of poor year classes that lead to stock declines. For many marine fish and invertebrate species, physical climatic and oceanographic factors can have direct effects on important population characteristics such as geographic distribution, reproductive success, growth, and recruitment. Ocean currents may carry eggs and larvae from spawning grounds to nursery areas or to areas unfavorable to survival. Entrainment into eddies and fronts may be essential to larval retention, survival, and formation of strong year classes for some species. For some species, the number, size, and stability of these ocean features determine the number, size, and productivity of fish/shellfish stocks (Sinclair 1988).

Changes in oceanographic conditions can also affect the geographic distribution and availability of a species. For instance, the geographic distribution of yellowfin sole has been related to the distribution of ice cover and formation of the cold pool (Bakkala 1993). As another example, chinook salmon bycatch in domestic groundfish trawl fisheries is associated with the shelf-break front over 200 m depth contour. Also, changes in oceanographic conditions, coupled to prey availability, can cause significant changes in growth rates. Decadal changes in the growth rates of Pacific halibut prompted major changes in recent assessments of stock size and annual commercial fishery quotas. Fishing can cause local depletions and may reduce overall stock abundance. When coupled to periods of low productivity, overfishing can reduce stocks so low that reproductive success may be jeopardized. For example, it is generally thought that Pacific Ocean perch were overfished by foreign fleets in the 1950s and 1960s. Even at more moderate harvest rates, fishing can truncate size and age distribution of fish stocks resulting in a large reduction of mean size and age of the population. The loss of older ages may have implications on reproductive success and on a population’s ability to withstand periods of poor recruitment.

Questions: How are decadal and annual atmospheric and oceanographic changes associated with periods of strong and weak recruitment of fish and invertebrate species? What are the specific mechanisms responsible for these associations? What is the effect of oceanographic conditions, such as cold pool, sea ice, or ocean fronts, on the populations, distribution, and growth of fish, invertebrates, birds and mammals? How can fisheries be maintained in light of decadal scale variability? What are the implications of these changes for multispecies and ecosystem-based management? How do different stocks of the same species in the Bering Sea respond to physical and anthropogenic perturbations?

Possible approaches: Use geographic information systems to analyze changes in species distributions with respect to temperature, cold pool, sea ice, and ocean fronts. Use acoustics, telemetry, and tagging to understand movements of animals relative to physical water characteristics. Determine winter diet and distribution of seabirds relative to sea ice. Incorporate geographic distribution, age composition, and environmental variables into analyses of stock-recruitment data. Conduct field studies to identify the roles of eddies and fronts on larval retention and survival. Conduct statistical and modeling studies on physical factors to investigate recruitment processes of important species. Incorporate environmental effects into

analyses of management strategies and harvest rates. Consider experimental management strategies in an attempt to separate the effects of fishing and environment on population trends. Different stocks for comparative studies may be identified by genetics, elemental analysis, analysis of fatty acids, and other methods.

### *Food web dynamics*

The Bering Sea ecosystem is dynamic, and the manner in which changes in nutrients affect it depends on species responses to climate and the timing and location of nutrient inputs. Varying climate conditions, including those that affect advection, mixing, and stratification, will influence the timing, location, abundance, and species composition of primary producers in the Bering Sea. Areas of upwelling, ocean fronts, and eddies can be regions where well mixed and stratified waters juxtapose to create optimal conditions for enhanced primary production. Species composition may be very important. Regions of high nutrients can lead to production of large phytoplankton cells such as diatoms, whereas regions of low nutrients can lead to small phytoplankton cells such as dinoflagellates. Changes in primary producers can translate into significant shifts in zooplankton distribution, species composition, and production. These production pathways are then translated through the food web to higher trophic levels of interest to commercial fisheries and subsistence users.

There are several ways in which changes in the phytoplankton community can be manifested in major changes in upper trophic levels. For example, communities of large phytoplankton can lead to efficient energy transfer to upper trophic levels and greater fish production due to short food chains, whereas communities of small phytoplankton can lead to long food chains, inefficient energy transfer, and reduced fish populations (Ryther 1969). Such changes can also be manifested in connections between pelagic and benthic food webs, i.e., whether the system is coupled or uncoupled. The PROBES program found that ineffective grazers live inshore of the middle front, thus much of the primary production falls ungrazed to support the bottom community. On the other hand, seaward of the middle front, grazers are effective, so much of the production gets consumed and remains in the pelagic realm. Shifts in the plankton community can lead to shifts between conditions favorable for commercially-important pelagic species (salmon, pollock) and benthic species (crabs, flatfish).

Recently, our basic understanding of energy flow at low trophic levels in marine ecosystems has been challenged. Much of what we know about dynamics of small organisms is limited to sampling with nets that capture relatively large-sized plankton. This sampling has led to the classical view of nutrients → net phytoplankton → zooplankton → fish. By developing new techniques for sampling plankton too small to be captured by plankton nets, scientists are revising classical views about the most important energy pathways in marine systems. For instance, in some oceans, cyanobacteria are not only the most important primary producer, but they also introduce more nitrogen into the euphotic zone than occurs by nutrient flux across the thermocline (Carpenter and Romans 1991). Yet, these and other very small plankton and their roles in energy pathways in the Bering Sea ecosystem are unknown.

At other trophic levels, much of our knowledge of food web dynamics comes from sampling selected species, such as stomachs of commercially-important groundfish species from assessment surveys in summer on commercial fishing grounds. Little information is available

during other seasons, in nearshore areas that serve as nursery areas for many fish and invertebrate species, and from non-commercial species. It is generally thought that fish recruitment is determined during early life; food availability and predation are two of the leading hypotheses about year class formation. Yet, little is known about perhaps some of the most important predators on early life stages of fish and invertebrates in the Bering Sea. Jellyfish and ctenophores are major consumers of larvae, yet virtually nothing is known of their abundance and associated predation mortality. Also, enhancement programs contribute to high salmon abundance, but little is known about salmon predation at sea. Likewise, little is known about other important predators, such as sea stars, sculpins, and others.

It is generally felt that declines of mammals and birds may be related to a reduction in the diversity of available prey species. Historical diet records on at least two species of pinnipeds and three species of marine birds indicate a marked shift in diet that includes an increase in consumption of juvenile walleye pollock and a decrease in consumption of other once predominant forage fishes. In addition, the size of pollock consumed by northern fur seals appears to have decreased since the 1970s. More recent declines in sea otter populations in the southern Bering Sea may reflect cascading effects of earlier mammal declines and further modified trophic interactions among apex predators. The structure of the Bering Sea groundfish community has also shifted in response to what has been termed a pollock-dominated system and a “juvenation” of the pollock resource. Unfortunately, the lack of baseline distribution and abundance data on forage fishes, such as capelin and eulachon, boreal smelt, and cephalopods, such as gonatid squid, limits current interpretation of the full impact of these apparent changes on mammals and birds and the rest of the Bering Sea ecosystem.

Clearly, improved knowledge of food webs and the processes that determine the various routes by which energy is transferred through the ecosystem will be important to developing ecosystem-based management approaches. Knowledge, or its absence, also has major implications on single-species fishery management decisions, as well. For example, area closures and reductions in the pollock fishery have been implemented due to concerns for effects on mammals, and in the yellowfin sole fishery to prevent disturbance of walruses and interference with herring on spawning migrations. However, the benefits of these area closures versus other alternative measures are unknown. A better understanding of food web dynamics will lead to improved fishery management decisions.

Questions: What are the dominant energy pathways in the Bering Sea that lead to managed living marine resources? How and why do they vary? What influence do predator-prey interactions have on ecosystem structure and dynamics at various time and space scales? What are current forage fish life histories and abundance trends? What are current distribution, abundances and trends of marine mammals and seabirds in summer and winter? What are population demographics and trends? Do climatic changes or fishing removals contribute to declines in marine mammal and seabird populations through localized depletion of prey or changes in prey species diversity? What diets characterize increasing versus decreasing marine mammal and seabird populations? What are prey abundances near rookeries with healthy populations versus those with declining populations? What limits annual availability of prey to seabirds? What are wintering areas of seabirds from specific colonies in the Bering Sea? Are observed declines related to factors affecting populations on their breeding grounds in the Bering

Sea, or to factors during the non-breeding season, possibly outside the Bering Sea? How do changes in prey availability and abundance affect predator populations? Which prey populations suffer the highest predation mortality? What are dominant predators on the early life stages of fish and invertebrates? How do climate shifts affect the timing of fish larvae with plankton production? What are the interrelationships between productivity in pelagic and benthic realms of the ecosystem? What is the effect of increased flatfish populations on epifaunal invertebrate populations? What are the associations between groundfish, crab, and shrimp abundance, and what are the relative roles of predation and competition? What are the effects of fishery discards on piscivorous predators and their prey? What are the effects of major salmon enhancement programs on other components of the ecosystem? What are the effects, if any, of removals of tons of carbon from the Bering Sea on long-term system productivity? What are the implications of trophic dynamics on multispecies management and ecosystem-based management?

Possible approaches: Develop monitoring programs for important plankton, forage, and predator species, perhaps in critical nearshore areas, that are not currently assessed by surveys and commercial fisheries, to identify their stock structure, status, and trends as key species in the Bering Sea ecosystem, using a variety of sampling techniques including net sampling, hydroacoustics, and stomach contents of predators to obtain abundance estimates. Conduct process-oriented studies and seasonal monitoring of important trophic interactions through diet analysis, stable isotope analysis, and other techniques. Design models ranging from minimal realistic models of specific species interactions to multispecies models to ecosystem models. Develop field and modeling studies to identify the causes of contrasting population trends of several key species with various life history strategies at different trophic levels in the food web. Use telemetry and other methods to define (horizontally and vertically) marine mammal, seabird, and apex predator feeding areas both in the Bering Sea during summer and in areas outside the Bering Sea that may be visited seasonally and to define the relationship of feeding areas to principal fishing areas. Identify and quantify food items. Evaluate the effect of fishing removals on local prey distribution and abundance. Develop spatial models of predator foraging and energetic models of prey demand. Study the effects of discards on benthic predator-prey dynamics in selected study sites.

#### *Contaminants and other introductions*

In comparison to shallow seas adjacent to more populated and industrialized parts of the world, the Bering Sea tends to have low levels of toxic contaminants. However, levels have been rising over the fifty years or more and especially more recently. This is partially due to increases in the release of contaminants related to activities within the region such as mining, fishing, and oil exploration. Also, there are instances of local contaminants, such as radioactive wastes in the Aleutian Islands. At least as significant, however, are increases connected to long-range transport of contaminants from more southerly regions. Ocean currents and especially atmospheric air movements can transport contaminants long distances before the contaminants are deposited. Such long-distance transport and deposition of contaminants has been clearly detected in the Bering Sea. A study of Aleutian green-winged teal revealed that 25% of the eggs collected had mercury levels high enough to cause deformities. Other contaminants in the system include PCBs, DDT derivatives, and oil. Oil spills can have devastating effects,

particularly on marine mammals and birds. Local ocean circulation may concentrate or conserve contaminants for extended periods.

This build-up of contaminants is of substantial concern because cold region ecosystems such as the Bering system are believed to be more sensitive to the threat of contaminants than are systems in warmer regions. Many of the contaminants are retarded in their loss in colder areas due to slower chemical break-down at lower temperatures and to the tendency of some of the more volatile organic contaminants that are deposited in cold regions to be trapped there. Also animals high in the food web and with relatively large amounts of fat, as is true for a number of the important marine mammals and sea birds in the Bering Sea, tend to concentrate organic contaminants, such as pesticides and PCBs, very strongly. Thus, these animals may be at substantial risk from contaminants even at environmental levels that are at or below concentrations that commonly occur in more temperate regions. Finally, there are concerns about human health in the region, particularly for Alaska Natives who rely on marine mammals and seabirds as food sources.

In addition to chemical contaminants, humans introduce other foreign material to the system. These include trash and plastics that may cause problems to animals who consume them or get entangled in them. Discarded or lost fishing nets and pots can entrap and kill animals for years. Introductions may be biological in the form of diseases or exotic species. Bitter crab disease is caused by a dinoflagellate that can be spread by transporting infected crabs from one area to another. Discharge of bilge water or live tanks has been found to introduce exotic species, sometimes with very adverse consequences on the native flora and fauna. Fish reared in hatcheries or enclosures can develop viruses that spread to natural populations when fish escape or are released.

Questions: What are the sources and fates of contaminants in the Bering Sea? What is the magnitude and extent of the long-range transport of contaminants to the Bering Sea? What are the trends in contaminant concentrations levels in the Bering Sea? How do contaminant levels, trends, and effects in the Bering Sea compare to the levels, trends, and effects found in other regions, especially other Arctic and subarctic areas? What are the effects of contaminants on the composition and functioning of the Bering Sea ecosystem? What direct and indirect effects do contaminants have on the populations of living marine resources and protected species of the Bering Sea? How do contaminants in living marine resources affect the health of individuals and communities reliant on Bering Sea resources?

How much foreign material (plastics, trash, etc.) is discarded in the Bering Sea? What are the effects of ingestion of these materials on animals? How much fishing gear is lost in the Bering Sea? What are the effects of this lost fishing gear on fish, invertebrates, birds, and mammals? Have any exotic species been introduced into the Bering Sea, and what are the risks to native species? How can risk of introduction of exotics and spread of diseases and viruses be minimized?

Possible approaches: Survey contaminant levels and indicators of contaminants effects in the major components of the Bering ecosystem to assess distribution of contaminant concentrations and of the effects they cause. Establish a series of locations where long-term seasonal monitoring of contaminant levels in various media (i.e., air, water, sediment, various types of biota) is



conducted on a long-term continuing basis. Conduct controlled field and laboratory experiments to assess the biological consequences of exposure to the levels of contaminant detected in the Bering Sea paying particular attention to evaluating the reproductive and other effects of endocrine disrupting organic contaminants. Augment ongoing monitoring programs for contaminants in subsistence on commercial fish harvests. Survey lost fishing gear, its condition, and document entangled species. Sample ballast water for exotic species, and survey the Bering Sea for presence of those species. Consider improving current regulations concerning transport of ballast water, and garbage and waste disposal by fishing and merchant vessels.

### *Habitat*

Habitat is critical to fish, invertebrate, mammal, and bird populations and their productivity. Habitat influences growth, reproduction and survival rates of animals. Depending on the particular species, habitat may include physical characteristics of the bottom, grain size, and biological characteristics. A certain type of habitat may be necessary for spawning, a different type may be necessary for survival of the early life stages that are most vulnerable to predation, and yet another type may be needed for juvenile and adult growth. Thus, identification of habitat requires sufficient knowledge to evaluate all major phases in the life history for each species of interest.

Furthermore, fishing may have direct and indirect effects on habitat and the bottom community of plants and animals that contribute to that habitat. Whether trawling and dredging causes detectable short-term and long-term effects depends on the weight of the gear, the degree of contact with the bottom, depth, ocean currents, bottom type, and the biological community living in the area (Messieh et al. 1991; Jones 1992). Because effects depend so much on these factors, research specific to the Bering Sea fisheries is seriously needed. In some other regions, fishing gear has been shown to scrape and plough the sea bottom, suspend sediment, and damage physical and biological structures (e.g., attached plants, corals, worm tubes, tunicates) important to survival of some species. Damaged and injured benthic species may attract predators, such as sculpins, starfish, flatfish, and crabs (Caddy 1973), thus favoring growth and survival of some species to the detriment of others. In some cases, organic matter becomes buried causing a shift away from aerobic energy pathways at the sediment-water interface that are important to fish production toward anaerobic subsurface respiration by bacteria (Mayer et al. 1991).

In addition, coastal development can adversely affect important habitats located in estuaries, embayments, and shallow and intertidal waters along open coastlines. Development and fishing activities may disrupt marine mammals and birds through several routes including disruption of nearshore habitat that may be important foraging areas for lactating, nesting, or young-of-the-year animals. Humans may introduce contaminants, remove vegetation that serves important filtering purposes, or disrupt breeding or nesting animals. Habitat research will ultimately improve our ability to develop baseline data to assist in planning future coastal development, predict changes in stock status, provide protection of presently adequate habitat, and make necessary improvements to degraded habitat that will maintain and improve stock status.

Questions: What are the habitat characteristics of various life stages of important fish species? What are the nearshore habitat requirements of otherwise pelagic marine mammals and seabirds, both in terms of their role as buffer zones and as sources of prey availability for young of the

year, lactating or nesting adults? What is the role of fixed invertebrates on the survival of different commercially-important species? Where are fish habitats in the Bering Sea? What influences change in their extent? How does fishing impact physical habitat attributes? What effect does fishing have on bottom-dwelling invertebrates and plants? What marine mammal, seabird, and fish habitats are located in areas likely to be affected by coastal development?

Possible approaches: Conduct survey of physical and biological characteristics of fish habitat for important fish species and life history stages. Use geographical information systems to map important habitats, locations of renewable and non-renewable resources, and to evaluate fishery and coastal management options. Assess biomass of aquatic vegetation which provides important habitat (e.g., herring spawning), but which is also subject to commercial harvest. Perform controlled studies of fishing effects on habitat and bottom organisms on different bottom types, and examine short-term and long-term effects on benthic predator and prey populations. Consider establishing refuges as areas for distinguishing fishing from natural changes in bottom habitats and biological communities. Evaluate current fishing area closures with respect to the location of important habitats.

### **Present research needs**

The research questions outlined above encompass a wide range of research activities that would be difficult for any one research program to accomplish. Also, some of the questions are already being considered, at least in part, by some presently funded programs. A summary of presently funded cooperative programs is provided in the appendix in order to identify some of the unfunded needs for a cooperative research program relating to the fisheries or marine ecosystems in the Bering Sea. Data gaps and research priorities were summarized in the proceedings of the Dec. 4-5, 1997 Bering Sea Ecosystem Workshop (see the appendix for workshop description) and are summarized below as a first step in identifying the most critical data gaps and research needs for the Bering Sea. Further refinement of these gaps and priorities needs to be done and may be a focus of a future workshop on this plan.

#### *Data gaps and research priorities*

Detailed tables and text outlining specific data gaps and research priorities were developed for the proceedings of the December 4-5, 1997 Bering Sea Ecosystem Workshop. These gaps and priorities can be grouped into the following categories: long-term monitoring, research to address acute management issues, and research to address longer-term management concerns.

#### Long-term monitoring

Lack of long-term time series of many important ecosystem attributes was the most frequently mentioned data gap. With respect to physical data, a year-round observational system is needed to address questions related to nutrient renewal in the Bering Sea. Moorings, which provide time series information on biophysical attributes are also needed to understand biophysical processes. Lower trophic level animals (which include primarily phytoplankton and small benthic and pelagic invertebrates ) have been a largely neglected component of monitoring programs of the Bering Sea. Short time series exist for some of these but require a standardized, long-term monitoring approach. Several crab and scallop species are not presently being monitored. Seasonal monitoring of seasonal distribution of forage species, including squid, juvenile pollock, herring, capelin, smelts, sandlance and myctophids, and the seasonal abundance, distribution, and diet of their predators was identified as high priority. Assessing the

distribution of juvenile groundfish, particularly flatfish, rockfish, and sablefish, was an area requiring attention and which could further goals to identify essential habitat areas for these life history stages. Mapping of physical habitats of groundfish is also needed. Monitoring the distribution and abundance of primary subsistence resources: beluga and bowhead whales, and ice-associated seals, is crucial. An integrated program for systematic monitoring of the levels, trends, and adverse biological effects of contaminants is needed. Seasonal monitoring of winter distribution and diet of seabirds is a priority. Developing methods to census and monitor auklets and other crevice-nesting seabirds is needed to produce reliable abundance indices for these animals.

#### Research to address acute management issues

Develop alternative harvesting strategies for invertebrates. Continued assessment of northern fur seal interactions with commercial fisheries. Evaluate the effect of fishing removals on local prey distribution and abundance. Evaluate the impact of fishing on benthos. Studies on the winter and spring foraging behavior of sea lions along with abundance and distribution of their prey are necessary along with sea lion physiology and genetics in order to determine causes of sea lion declines. Interdisciplinary research is needed to understand the factors that limit food availability and quality for key bird and mammal species during the breeding season and winter. Research to develop better abundance estimates of Atka mackerel is needed given its importance for sea lions and fisheries. Research to identify seasonal movements of groundfish, particularly walleye pollock, Pacific cod, and halibut were high priority and had strong links to management concerns about these stocks.

#### Research to address longer-term management concerns

Projects identified here are varied. For lower trophic level animals, determining vital rates to estimate production and major pathways of carbon cycling during all seasons was identified as high priority. Taxonomic work on many benthic groups was identified as a high priority to be done before commencing monitoring. Understanding causes of recruitment fluctuations of commercially important invertebrates is a much needed research item given the value of these fisheries and costs associated with fishery collapse. Processes influencing mortality of Pacific salmon were identified as one of the least known types of information available for this group. Determining predator-prey relationships of cod and crab was mentioned in both the cod and crab high interest topic areas. There is a need to understand recruitment processes of groundfish such as Greenland turbot, arrowtooth flounder, halibut and rockfish. Studies to describe and compare migration patterns and foraging ecology of northern fur seals are of primary importance along with studies to examine the effects of disease on population trends. Projects to estimate adult bird survival rates are required since data from other areas may not apply to the Bering Sea. Conduct controlled field and laboratory experiments to assess the biological consequences of exposure to the levels of contaminant detected in the Bering Sea paying particular attention to evaluating the reproductive and other effects of endocrine disrupting organic contaminants.

### **Implementation issues**

#### *Program products*

It is paramount that information collected by researchers be available to stakeholders and other public in a timely manner. This can be accomplished by dissemination of field plans, experimental results, and database links through the world wide web. Real-time biophysical

measurements must also be made available via the web to aid in communication and direction of field programs conducted by different research entities and to provide information on the status of the ecosystem to the community. Some long-term monitoring is well suited for real-time dissemination, e.g., data from moored biophysical platforms, satellite-tracked marine mammals and drifting buoys, and ocean color sensors. The on-going results of all monitoring activities must be integrated to provide an annual report on the status of the Bering Sea. Community involvement in research is vital and can be accomplished in a variety of ways including use of traditional knowledge in identifying monitoring priorities, identification of scientific questions specific to local communities, participation in data collection and monitoring activities, and entering collected data via interactive web sites, .

Inclusion of traditional ecological knowledge is an important aspect of the program. Local and traditional ecological knowledge is important to scientists and managers because local people have a long history of observations in the area. The familiarity of local people with an area provides them with a background to recognize out-of-the-ordinary conditions. This kind of information provides scientists and managers with important information they may not be able to obtain otherwise. Many scientific programs in Alaska have developed protocols for including traditional ecological knowledge into the process. Some of the protocols developed for these programs may have utility for the present research program. However, decisions about the nature and scope of the protocols will require direct input from the Native communities involved and may require funding for Native communities to further develop and reach agreement on TEK protocols.

In addition to scientific products, adaptive managerial strategies that allow active management of human use of the ecosystem are essential to the program. To benefit both management and science, the program should support the development of new technologies. Some examples are remote sensing of sea surface salinity and biological populations; moored nutrient sensors; and enhanced methods of sampling and tracking forage fishes, cephalopods, and apex predators. Ecological models can be a valuable tool in support of management and scientific understanding. Sound ecological models require the incorporation of monitoring data and process-oriented research to establish critical rates.

#### *Program management structure and support*

Key aspects of implementing research on the Bering Sea ecosystem are: sustained research support, coordination, communication, and involvement of local communities and stakeholders, and other public. Experience has taught us that certain management structures and support will insure the highest degree of success for this interdisciplinary, interagency program. Overall program management will be provided by the North Pacific Research Board. A successful program will also require a staff to handle program administration, including budget management, coordination of field programs, communications, public interactions, and other activities. Design of the management program is beyond the scope of this research plan. However, we envision the establishment of advisory groups as one of the vehicles for industry leaders, members of the environmental community, and other interested public to provide direct advice to the Board about research needs and priorities. Additionally, a successful science program requires an open and independent peer-review process. A scientific advisory committee should be established to help guide the science program, to coordinate peer review of research

proposals, and provide technical advice to the NPRB based on the breadth of scientific expertise on the committee. There are a number of nationally-recognized peer reviewed granting agencies (e.g., National Science Foundation, Saltonstall-Kennedy Program, Sea Grant, etc.) that could provide templates for the peer review process. Alternatively, the Board might consider the possibility to establish the frameworks for the science plan, but then to turn over administration of the peer-review process to an established body such as the National Science Foundation. Regardless of the particular structure, it is imperative that research is administered by a credible scientific review process.

Additionally, communication among researchers and between researchers and other groups is important. An annual science and technology workshop should be held each fall in Anchorage, Alaska, with an agenda including scientific program reports, status of technology developments, synthesis of community input, and field research planning. One product of the workshop could be information to form an annual report to disseminate results more widely and to document program achievements. Other communication methods include the use of NOAA's Bering Sea theme page on the world wide web to disseminate research information and the Bering Sea Ecosystem Project's listserve to distribute local knowledge observations and to initiate informal discussions about important issues.

We choose not to direct how traditional or local ecological knowledge enters into the implementation process. We will seek input from the local and Native communities on how best to incorporate TEK into the research and implementation plan. We do foresee, however, that local people will play a key role in the study of the Bering Sea ecosystem. The Pribilof Islands, for example, provide a natural laboratory at a site that is a pulse point in the ecosystem. With appropriate support, training, and facilities, local people could monitor the physical, chemical and biological features year round.

### **Funding Issues**

The North Pacific Research Management Board will need to consider several issues with regard to funding. One key issue will be how to allocate funds in order to support long-term monitoring programs, applied research to answer critical management questions of present concern, and more basic research to further understanding of ecosystem processes. Stability of funding across time is essential to the development and maintenance of long-term monitoring programs. Also, investigators involved in both basic and applied research may require funding for more than one year. Development of mechanisms for multi-year funding will be crucial to the success of the program.

### **Impediments**

Comprising almost 1 million square miles and surrounded by remote, minimally developed, islands and coastline, the Bering Sea will require both platforms and staging areas to conduct ecosystem specific research. Access to ports for vessels and airports for aircraft are both available, yet limiting, in the area. Competition for pier space during the fishing season, logistics support, and availability of commercial flights all factor into mounting an ecosystem study. Yet, as these issues can be managed, the lack of research vessels appears as the major impediment to a multi-seasonal ecosystem research program.

Historically, research vessels have been involved in the Outer Continental Shelf Environmental Assessment Program (OSCEAP), the NMFS Fishery Resource Surveys, the Fishery Oceanography Cooperative Investigation, and specific oceanographic or resource oriented studies. Presently, research vessel time has declined to 210 days of Resource Assessment and FOCI on one large federal vessel (MILLER FREEMAN), 130 days on one small federal vessel (TIGLAX) for Maritime Refuge support, and 90 days on one small State University vessel (ALPHA HELIX) (Figure 1). While both federal vessels are fully committed to the management mandates, limited time may be available through the University vessel. However, the limited time available may not be adequate for work planned for the Bering Sea. Alternative vessels, including excess NOAA vessels (CHAPMAN) or limited use UNOLS vessels (ENDEAVOR) may provide interim solutions. To address the crucial scientific issues, adequate research platform time needs to be planned. Whether through dedicated federal vessels, increased funding for University vessels, or through contract of vessels of opportunity, adequate research vessel time remains an impediment to mounting a field program.

Similarly, logistics and staging for an increase in the long term ecosystem research for the Bering Sea will require onshore infra-structure that enables staging and de-staging cruises, gear preparation and storage, and offices for pre- and post-cruise coordination. Improved facilities at Dutch Harbor, Alaska, either through contract or as public assets, should be considered to insure efficient use of vessel time, minimize delays with travel, and allow pre-cruise planning between multiple investigators. The present lack of onshore infra-structure in the research area remains an impediment to multi-agency, multi-disciplinary research cruises.

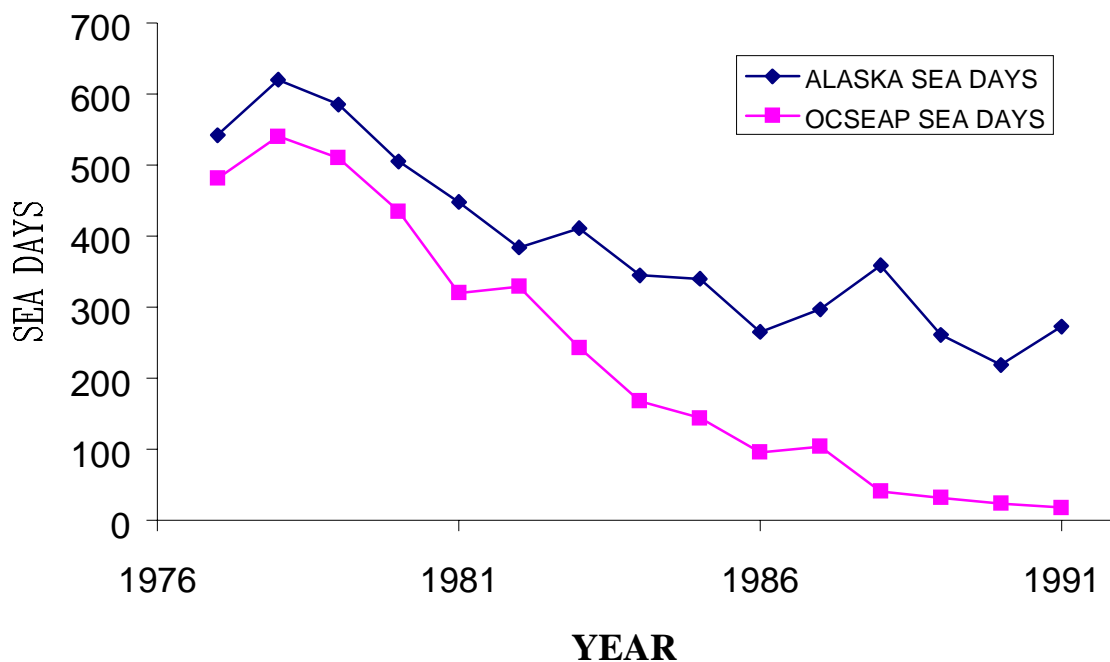


Figure 1.—NOAA ship use for open ocean ecosystem research in Alaska: 1977-1991.

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## **Appendix: Review of recent research plans, workshops, and cooperative studies**

### *National Research Council*

As a result of concerns about how living resources in the Bering Sea have been and should be managed, the NRC was asked to assess the current scientific understanding of the Bering Sea. The NRC appointed the Committee on the Bering Sea Ecosystem to study population dynamics and changes in marine mammals, birds, and commercially-important species in the ecosystem, and to ascertain the probable causes of the changes, gaps in knowledge, and research needs. The committee published its report in 1996.

Fish populations and other components of the ecosystem appear to react to many different environmental variables in the atmosphere and ocean. Overall, the committee concluded that climate-driven variability in the Bering Sea ecosystem is significant, occurs at many different time scales, and appears to affect many ecosystem components. It appears that climate has caused relatively rapid shifts in the organization of this marine ecosystem, and that changes over periods of decades may have larger effects than those over yearly periods.

Fishing and hunting of marine mammals by Aleuts and Eskimos have occurred for hundreds of years or more. Exploitation by indigenous peoples affected the abundance and community structures of marine resources, especially close to shore. Intensive exploitation of Bering Sea marine resources by the United States, Russia, Japan, and other nations began in the eighteenth century and increased in the nineteenth and twentieth centuries. This exploitation led to more severe local food shortages and even starvation among the indigenous peoples. Large-scale intensive exploitation of whales occurred during the 1950s, 1960s, and early 1970s. During this period, trawl fisheries severely reduced populations of eastern Bering Sea shelf flatfishes and slope rockfishes. The committee concluded that the most likely explanation of events over the past few decades in the Bering Sea ecosystem is that a combination of changes in the physical environment acted in concert with human exploitation of predators (whales, fish) to cause pollock to dominate the ecosystem - The Cascade Hypothesis.

Scientific questions posed by the NRC Committee on the Bering Sea Ecosystem are:

1. What are the nature and causes of the dynamics of pollock in the northeastern Pacific and Bering Sea over the past 50 years? Examine the plausibility of the Cascade Hypothesis as a scenario for ecosystem dynamics using models; examine short and long-term effects of commercial fishing through adaptive management and modeling, respectively; examine roles of top-down and bottom-up forcing; examine relationships between pollock and other forage fishes; examine at-sea ecology of mammals and birds and how that ecology is influenced by pollock and other forage fishes.
2. What is the role of ice in structuring the Bering Sea ecosystem? What are habitat requirements of invertebrates; effects of seasonal and interannual dynamics of ice on invertebrates?
3. What are the periodicities of ecosystem changes? Consider physical attributes, i.e., position of the Aleutian Low, ocean circulation changes, and sea surface temperature; and ecological attributes, i.e., distribution and abundance of marine mammals, seabirds, fish, benthic invertebrates, and plankton.

4. How do lower trophic levels of the ecosystem interact? Planktivorous birds (and fishes, if their place and time of collection are carefully documented) can be used as samplers of planktonic species.
5. What are the structure and functioning of the "green belt?" To what degree does it support productivity of various parts of the Bering Sea ecosystem? What physical and biological features make it so productive relative to other areas in the Bering Sea? Do changes in the green belt affect the various areas in a related way?

#### *Bering Sea Impacts Study*

BESIS, a project of the International Arctic Science Committee (1997), is an international synthesis effort to assess regional impacts of global change in the Western Arctic/Bering Sea region, from the Mackenzie River to the Lena River. The underlying philosophy of BESIS is that impact assessments provide an excellent means of interdisciplinary analysis and synthesis of global climate change. BESIS addresses impacts on fisheries, marine ecosystems, subsistence hunting and fishing, terrestrial and freshwater ecosystems, non-renewable resource diversity of social and cultural issues. There is a BESIS project office located at the University of Alaska Fairbanks, and another at the Pacific Oceanological Institute in Vladivostok, Russia. While BESIS may become a vehicle for funding research, at the present time it does not function in that mode.

Participants from the U.S., Russia, Japan, Canada and China provided some insight into impact assessment during a workshop held in September 1996. The approach and a list of highly condensed scientific questions follow. After listening to a series of presentations regarding the status of knowledge in the Bering Sea with respect to climate change, workshop attendees were divided into four groups. These groups: Climate, Snow and Ice; Coastal and Marine Ecosystems; Economic Effects; Native Culture and Subsistence, then convened to deliberate on future research. The first three groups established 60 research recommendations or questions. The fourth group determined that "the trust of Native knowledge work must eventually be more thoroughly discussed by the other groups" and did not provide a list of research priorities.

Three general topics which require further research appeared in at least two of the BESIS groups. These can be integrated into the following general questions:

1. How will global climate change affect the flux of nutrients onto the shelf? What are the implications of a reduced flux on nutrient-phytoplankton-zooplankton dynamics [including species composition and changing population dynamics] and transfer to higher trophic levels? Will the carrying capacity of the eastern Bering Sea shelf decrease under a warming scenario?
2. How will global climate change affect seasonal sea ice? How will decreases in extent, thickness, and timing of advance/retreat influence biophysical processes throughout the food web and distributions of fish, birds and mammals?
3. How will global climate change affect sea level? Will the expected rise in sea level significantly alter coastal habitats? Will the steric level increase in the Arctic exceed that in the North Pacific so that transport through Bering Strait diminishes? Will this markedly impact the flux of water/nutrients onto the shelf, thereby diminishing carrying capacity?

### *Arctic Monitoring and Assessment Program (AMAP)*

AMAP has a goal to monitor the levels and assess the effects of selected anthropogenic pollutants in the Arctic (Stone 1997). In comparison with most of other areas of the world, the Arctic remains a clean environment. However, potential impacts in the Arctic may be great because of vulnerability of species to stress and relatively greater exposure of animals high in the food webs. The major concern at present is PCBs and pesticides. The Bering Sea was not selected as a major geographic area of concern.

AMAP's recommendations are to:

1. Better quantify the input to, and significance of, the different pollutant pathways to the Arctic.
2. Promote the design and establishment of a coordinated circumpolar network of long-term reference monitoring sites for contaminants and pollutants.

### *Global Ecosystem Dynamics*

U.S. GLOBEC was developed to study the effects of climate variability and change on marine ecosystems. It has ongoing studies on the Antarctic, Georges Bank and North Pacific (U.S. GLOBEC 1996a, 1996c) ecosystems. Through GLOBEC's science plan (U.S. GLOBEC 1996b), it is proposing a similar study in the eastern Bering Sea, which would commence in 1999. This study will build on NOAA Coastal Ocean Program's Southeast Bering Sea Carrying Capacity, and compliment the other U.S. GLOBEC regional studies. Several reasons were given for choosing the Bering Sea, e.g., the impact of climate change will be strongest in northern latitudes, the Bering Sea supports large fisheries which are sensitive to climate variability, and major shifts in the Bering Sea ecosystem are presently occurring. The overall goal of the study is to understand the effects of climate variability and change on the distribution, abundance and production of marine animals in the Bering Sea. The approach is to study the effect of past and present climate variability on the ecosystem and use this information as a proxy for how the system may respond to future climate change. Key taxa to be investigated are copepods and euphausiids. Retrospective, modeling, process-oriented, and monitoring approaches will be used. New technology will also be developed.

Key GLOBEC issues are:

1. Is zooplankton production controlled by physical processes (advection, stratification, sea ice coverage and water temperature [extent of cold pool]) and/or is it controlled by biological processes related to the distribution and abundance of predators?
2. Is production in the Bering Sea coupled to that in the Gulf of Alaska through physical forcing?
3. Do interannual and interdecadal changes in physical forcing impact top level predators by altering survival of prey species?
4. Are mesoscale circulation and sea ice formation the dominant physical factors controlling zooplankton dynamics on the shelf?

### *North Pacific Marine Science Organization*

PICES hosts an international GLOBEC program on Climate Change and Carrying Capacity (CCCC: North Pacific Marine Science Organization 1996). The main purpose of the CCCC program is to integrate and stimulate national activities on the effects of climate variations on the

marine ecosystems of the subarctic North Pacific. This program has developed a science and implementation plan to address how climate change affects ecosystem structure, and the productivity of key biological species at all trophic levels in the open ocean and coastal North Pacific ecosystems. There is a strong emphasis on the coupling between atmospheric and oceanic processes, their impacts on the production of major living marine resources, and how they respond to climate change on time scales of seasons to centuries. The implementation plan has outlined several central scientific issues around physical forcing, lower trophic level response, higher trophic level response, and ecosystem interactions. It has been recognized that the comparative approach would be a key ingredient to the study of the central scientific issues. The eastern and western Bering Sea regions are two of the ten regional ecosystem components considered by the CCCC program and a recent workshop held by the REX (Regional Experiment) task team of the CCCC program identified several comparative studies that could be performed, including several focusing on comparisons between the eastern and western Bering Sea regions.

Important scientific questions identified by PICES - CCCC include:

1. What are the characteristics of climate variability, can interdecadal patterns be identified, how and when do they arise?
2. How do primary and secondary producers respond in productivity, and in species and size composition to climate variability in different ecosystems of the subarctic Pacific?
3. How do life history patterns, distributions, vital rates, and population dynamics of higher trophic level species respond directly and indirectly to climate variability?
4. How are subarctic Pacific ecosystems structured? Do higher trophic levels respond to climate variability solely as a consequence of bottom up forcing? Are there significant intra-trophic level and top down effects on lower trophic level production and on energy transfer efficiencies?

PICES established a Bering Sea Working Group (WG) from 1993 through 1996 to provide a focus for cooperative, international research in the region. The WG noted that advances in understanding the Bering Sea as a system would primarily develop through recognition of the complexity of the ecosystem as a whole. The consensus of the group noted that the abundance of species fluctuated widely and that integrated physical and biotic studies are required to understand the nature and reasons for such fluctuations (North Pacific Marine Science Organization 1997).

To stimulate international, cooperative research, the PICES WG recommended five areas for study:

1. Understand the mechanisms behind decadal scale change and possible amplified effects in the biological response. For example, could there be an alternation in dominance of shelf production between benthic versus pelagic components of the ecosystem? What is the future role of pollock?
2. Improve understanding of the interchange between the North Pacific Ocean and the Bering Sea and the role of the deep basin as a repository for global deep water.
3. What are the mechanisms for biophysical exchange between the deep basin and shelf waters?
4. How does the presence of sea ice increase biological productivity?

5. What is the biology of predator-prey relationships? For example, are there seasonal changes? What are key nodal species in the benthic and pelagic food webs? Will fishing have the potential to substantially alter natural food webs?

*Alaska Research Plan, Alaska Regional Marine Research Board, 1993*

In 1991 Congress enacted the Regional Marine Research Act which established nine Regional Marine Research Programs around the country. The purpose was to “(1) set priorities for regional marine and coastal research in support of efforts to safeguard the water quality and ecosystem health of each region; and (2) carry out such research through grants and improved coordination.” Subsequent to a science planning workshop held in Fairbanks, Alaska, during March 10-11, 1993, a research plan was developed (ARMRP 1993). Unfortunately, beyond receipt of a \$50,000 planning fund, the Alaska Regional Marine Research Program was not funded by Congress.

The plan covered five major sections: (1) an overview of the marine environmental quality in the region; (2) an inventory of current research activities; (3) a statement of the research needs and priorities within the context of a 10-year goal; (4) an assessment of how the plan will incorporate existing research and management in the region; and (5) a description and schedule of the research objectives for the region during the 4-year period covered by the plan.

The Board identified the following four program goals and examples of specific research objectives:

1. Distinguish between natural and human-induced changes in the marine ecosystem of the Alaska region.
  - Investigate physical and biological factors that affect recruitment, growth, and survival of key marine species.
  - Investigate linkages between pelagic and benthic food chains
  - Determine the effect of human-induced factors such as fishery harvest (predator or prey removal), damage to the environment (e.g., trawling, habitat alteration), enhanced competition (through hatchery stocks), or water quality (pollution) on recruitment, growth, and survival of key species.
2. Distinguish between natural and human-induced changes in water quality of the Alaska region.
  - Develop techniques, tools, and indicators which will enable scientists in the region to determine when water quality has been degraded such that it affects the health of the marine ecosystem.
  - Determine whether increasing incidences of biotoxins in fish and shellfish are related to natural change, human-induced change, or increased analytical capabilities.
3. Stimulate the development of a data gathering and sharing system which will serve scientists from government, academia, and the private sector in dealing with water quality and ecosystem health issues in the region.

4. Provide a forum for maintaining and enhancing communication between the marine scientific and management communities on issues related to maintaining the region's water quality and ecosystem health.

*Alaska Environmental Studies Strategic Plan, FY 1999-2000, Minerals Management Service*

The Alaska Environmental Studies Program was initiated by the U.S. Department of the Interior in 1974 in response to the Federal Government's decision to propose areas of Alaska for offshore gas and oil development. The purpose of the program is to define information needs and implement studies to assist in predicting, assessing, and managing potential effects on the human, marine, and coastal environments of the outer continental shelf and coastal areas that may be affected by gas and oil development. Lease-management decisions are enhanced when current, pertinent, and timely information is available. The Environmental Studies Program then monitors any effects during and after oil exploration and development. Since program inception, more than \$250 million have been spent on Alaskan studies in the Arctic, Bering Sea, and Gulf of Alaska.

Early in the development of the program, the focus was on obtaining information on the vast biological resources and physical characteristics of the Alaskan environment for pre-lease decision-making. As a broader base of information was established, it became possible to focus on more topical studies in smaller areas to answer specific questions and fill identified information needs. As more disciplinary data were collected and analyzed, the importance of taking an integrated, interdisciplinary look at complete ecosystems in sensitive areas became apparent. The Minerals Management Service (MMS) has involved Alaskans and others in research planning and execution in a number of ways. In all MMS field-oriented studies, researchers coordinate directly with local communities, and traditional knowledge has been incorporated into specific study planning, field work, and interpretation of results.

Areas covered by the Alaska Environmental Studies Program include: (1) physical oceanography; (2) fate and weathering of spilled oil and the effects that oil spills may have on marine habitats and biota; (3) life history, food habits, and abundance and distribution of seabirds, fish, and invertebrates, as well as their interaction with oil and gas activities; (4) protected species of marine mammals; and (5) social and economic studies, including subsistence, on the effects of oil and gas exploration and development. In the most recent strategic plan (MMS 1997), MMS identified the long-range information needs for the Beaufort Sea: potential disturbance of bowhead whales and other wildlife; effects of petroleum activity on native culture; and pollutants as potential contaminants of food supply. For Cook Inlet, long-range needs include water and sediment quality; the effects of oil spills, discharged pollutants, and construction activity on lower trophic level organisms; effects of oil spills on fisheries resources; socioeconomic concerns about oil and gas activities, and cumulative effects on resources. For both regions, there is a long-range need to develop an environmental database. The plan also lists specific topical areas for proposed future research.

*Long-term Plan for Crab Research in Alaska, 1995*

Staffs from the Alaska Department of Fish and Game, National Marine Fisheries Service, University of Alaska Fairbanks, and University of Washington have met annually since 1992 to



discuss ongoing crab research and future research planning. Research plans have been developed and revised periodically. The most recent long-term research plan (Kruse 1996) prioritizes crab research into four broad areas: (1) stock structure; (2) population estimation; (3) stock productivity; and (4) harvest strategies.

Specific research topics addressing stock structure include attempts to distinguish stocks of geographically-close areas such as king crabs within the Kodiak and Alexander Archipelagos, Tanner crabs in Bristol Bay versus Pribilof Islands and in Kachemak versus Kamishak Bays of lower Cook Inlet, and hybridization among snow and Tanner crabs. *Population estimation* research topics include application of new length-based analyses to assess Alaskan crab stocks; development of fishery-based assessment methods using onboard observer data; and development and application of laser line scanning systems for assessment of trawl and pot catchability, crab associations with their habitats, and other topics.

Much crab research is needed on stock productivity, including: estimation of natural mortality such as predation; development of a retainable tag to study growth of brachyuran crabs; growth studies of Tanner crabs, snow crabs, and blue and golden king crabs; studies of reproductive biology; crab recruitment processes as related to spawning stocks, predation, competition, and oceanographic conditions; red king crab habitat as defined by biological communities and effects of fishing on these habitats; and additional fishing-related studies on handling mortality, ghost fishing by lost gear, and others. Needed research on harvest strategies include modification of fishing gear to reduce bycatch, and experimental management and population simulation models to evaluate radically different harvest strategies.

### *Workshops*

A. Proceedings of the workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea, October 18-21, 1983, Anchorage, AK. Alaska Sea Grant Report 84-1, University of Alaska, Fairbanks, Alaska 99775, April 1984.

This report documents the discussion of workshop participants, convened by Alaska Sea Grant, on the interactions between marine mammals and four types of fisheries in the southeastern Bering Sea: groundfish, herring, salmon, and shellfish. The objectives of each group were to: 1) identify marine mammal species that are known to be or could be affected by the fishery; 2) indicate the nature and probable significance of the interactions; 3) determine whether existing data, models and research/monitoring programs were sufficient to predict, detect, and mitigate any possible adverse effects of interactions on marine mammals, the exploited species, or the fishery; 4) identify any critical data gaps; 5) suggest how critical data gaps could be filled; and 6) rank research needs in order of priority. High priority research needs of each of the groups were: feeding ecology of marine mammals; distribution (both geographically and with depth) and diet of marine mammals by area, season, age and sex; and population dynamics and factors affecting recruitment and distribution (seasonal and geographic) of both exploited and non-commercial prey species. Recommended methods of obtaining data on feeding ecology of marine mammals included tagging/tracking studies and analyses of stomach contents, scats and teeth to determine what is being eaten where and by whom, and oceanographic and biological surveys to determine the abundance, distribution and species composition of the prey available to marine mammals at the same times and locations.

B. National Marine Fisheries Service program development plan for ecosystems monitoring and fisheries management, NMFS, Washington, DC, September 14, 1987.

This plan provides a discussion of the general considerations involved in the development and implementation of broad-scale ecosystem programs. Although written from a national perspective, the contents are relevant to a program tailored specifically for the Bering Sea. The plan includes descriptions of the underlying justifications for such programs, a template for program structure, and program management considerations. An appendix includes an outline of ecosystem research topics and data needs, which was used as a framework for the construction of the Bering Sea Ecosystem Study Components section of the present document. Much of the step-down outline below was adapted from the NMFS Plan.

C. Uncertainties and research needs regarding the Bering Sea and Antarctic marine ecosystems, December 12-13, 1990, Seattle, WA. U.S. Dept. Commerce., Natl. Tech. Info. Serv. PB91-201731 (Swartzman, G. L., and R. J. Hofman), Springfield, VA 22161, July 1991.

This workshop was convened by the Marine Mammal Commission (MMC), in consultation with NMFS and Alaska Sea Grant, to: (1) identify critical uncertainties concerning the causes and possible relationships among the observed declines in various marine mammal and seabird populations in the Bering Sea over the previous 20 years, (2) identify the research that would be required to resolve the uncertainties; and (3) determine how experience in the Bering Sea/Gulf of Alaska and the Antarctic might be used to improve research planning and resource management in both area. Uncertainties in understanding and recommendations for research were listed for marine mammals, seabirds, fish and fisheries, and oceanography and primary production. Principal research recommendations for the first three biological components were improvements in techniques for estimating vital rates (e.g., size, mortality, births, energy flow) of populations (particularly for cetaceans, seabirds and some fish stocks, and in areas outside the Bering Sea for seasonal migrants), greater understanding of their seasonal distributions, and studies specifically designed to investigate the specific effects of fisheries on prey availability and population dynamics of fish and other species in upper trophic levels (including non-commercial species). With regard to Bering Sea oceanography and primary production, workshop participants recommended the establishment of a long-term monitoring program of primary, secondary and benthic production, as well as environmental parameters at a series of stations located on cross-shelf and slope transects in at least the western and northern Bering Sea. Participants also recommended that a formal or *ad hoc* working group, like CCAMLR (Convention for the Conservation of Antarctic Marine Living Resources) in the Antarctic, be established to plan and coordinate results of resource-related research in the Bering Sea and Gulf of Alaska.

D. Is it food? Addressing marine mammal and seabird declines, March 11-14, 1991, Fairbanks, AK. Alaska Sea Grant College Program Report AK-SG-93-01, University of Alaska, Fairbanks, AK, 99775, 1993.

The emphasis of this workshop organized by Alaska Sea Grant was to attempt to answer the dual questions of: Is food availability the key to declining marine mammal and seabird populations in the northern Gulf of Alaska and Bering sea?; and if so, What are the causes of reduced food availability (oceanographic/environmental changes, or human activities, principally fishing)? While workshop participants agreed that changes in quality and quantity of prey were most likely major contributors to observed declines in marine mammal and seabird population sizes,

no consensus was reached on the factor(s) responsible for such changes. Structured similarly to the workshop summarized in D above, the workshop subgroups recommended research in feeding ecology of marine mammals and seabirds, with specific attempts to ensure the availability of small or young fish as prey, improvements in methods and funding for studies to monitor species demographics (e.g., population size, age structure, vital rates), initiation of studies on distribution, population dynamics and nutritional value of non-commercial prey species, and expansion (seasonally and geographically) of pre-recruit surveys of commercial species (e.g. pollock).

#### E. Report on the Workshop on Enhancing Methods for Locating, Accessing and Integrating Population and Environmental Data Related to Marine Resources in Alaska.

The primary goals of this workshop were to:

- Identify the data types critical to the conservation of marine mammals and other marine resources in Alaska, and the organization collecting and maintaining those data.

- Determine how these data can be made available to other individuals and agencies.

- Describe current geographic information systems (GIS) used by different groups.

- Determine and recommend actions to develop a common or coordinated GIS or other data networks.

The workshop was held as a result of the findings of a 1992 study contracted by the Marine Mammal Commission entitled “Assessment and possible use of a cooperative/coordinated GIS to facilitate access to, and integration and analysis of, data bearing upon the conservation of marine mammals in Alaska.” The study results suggested that the development of a coordinated GIS would enhance the efficiency and utility of existing databases presently maintained independently by various agencies and organizations.

#### F. International Workshop on Future Crab Research Needs, 1995

In 1995, the Lowell Wakefield Fisheries Series included an International Symposium on Biology, Management, and Economics of Crabs from High Latitude Habitats. As part of the symposium, a workshop on crab research needs was convened (Paul 1996). Workshop participants identified a list of 39 research needs. Some topics overlap with other research lists (Kruse 1996); others included: role of climate in modifying food web structure; location of spawning, incubation, and nursery areas relative to recruitment; role of ocean currents in recruitment; improved understanding of population dynamics including stock-recruitment relationships; life history studies on lightly-exploited deepwater species and others using cost-effective remotely operated vehicles; fate of bycatch discards on the benthic environment; consequences of fishery alterations of size and sex structure of populations; socioeconomic tradeoffs of pulse fishing versus harvesting at lower, more constant levels; and use of refuges to propagate crab populations.

#### G. International Workshop on Future Rockfish Research Needs, 1986

A fisheries science symposium has been convened annually in Alaska since 1982 in honor of Lowell Wakefield who is recognized as the founder of the Alaskan king crab industry among other achievements. These meetings are organized by the Alaska Sea Grant College Program,

and other sponsors include the Alaska Department of Fish and Game, National Marine Fisheries Service, North Pacific Fishery Management Council, and occasionally other organizations depending on the symposium topic. Often these symposia conclude with a workshop on research needs.

In 1986, the Lowell Wakefield Fisheries Series included an International Rockfish Symposium, and a workshop was conducted on rockfish research (Clasby 1987). Workshop participants identified a number of needs, including: (1) lack of knowledge of the life histories of many rockfish species; (2) inability to forecast recruitment; (3) unknown accuracy and precision of biomass assessments; (4) multispecies fishery management; (5) bycatch of birds, mammals, and prohibited or fully-utilized fish species; (6) conflicts among user groups; (7) overlapping regulatory jurisdictions; (8) intra- and intersite variability of assessments; (9) accuracy of assessment models and surveys at low stock size; (10) incorporation of new biological and physical data into assessment models; (11) investigation of climatic effects on stocks; (12) use of experimental fisheries to test hypotheses; and (13) evaluation of costs and benefits of stock rebuilding.

#### H. International Workshop on Future Research Needs for North Pacific Flatfish, 1994

In 1994, the Lowell Wakefield Fisheries Series included an International Symposium on North Pacific Flatfish, and a workshop on future research needs was convened (Smith 1995). Workshop participants identified the following non-prioritized list of 13 research needs: (1) spatial analysis of catch per unit effort for Pacific halibut; (2) additional survey data to be correlated with commercial catch data; (3) potential conflict between commercial and sport halibut fisheries and its resolution; (4) bycatch and relationship with regulatory and economic discards; (5) cooperative research on Greenland halibut; (6) potential for arrowtooth harvest in Gulf of Alaska with acceptable bycatches; (7) does reproductive biology of flatfish drive abundance?; (8) age validation of flatfishes; (9) multispecies interactions of flatfishes with their prey, competitors, and predators; (10) assessment of archived data on flatfishes; (11) myxosporidean parasite as a cause of arrowtooth soft flesh; (12) genetic analysis of Pacific halibut; (13) human perturbations such as pollution and introduction of alien species.

#### I. International Workshop Future Research Needs for Forage Fishes, 1996

In 1996, the Lowell Wakefield Fisheries Series included an International Symposium on the Role of Forage Fishes in Marine Ecosystems, and a workshop discussion on future research needs was convened (Hay 1997). The chair of the workshop concluded with the following non-prioritized list of 8 research needs: (1) need for better ecosystem modelers; (2) bioeconomic models with long-term perspectives; (3) forage species-fish predator interactions; (4) improved communication of our science to public and government; (5) retrospective ecosystem analysis; (6) improved understanding of natural mortality processes; (7) distinguish between fishery and environmental changes; and (8) better data on lower trophic levels.

#### J. Bering Sea Ecosystem Workshop Report , NMFS, DOI, ADF&G, April 1998

This workshop was held on December 4-5, 1997 in Anchorage to promote research coordination and data sharing among organizations that study and utilize resources of the Bering Sea. Organizations including NOAA, Department of Interior, Alaska Department of Fish and Game, EPA, University of Alaska, and Alaska Native groups presented their research projects, data bases, and data gaps. Following the workshop, an interagency Bering Sea Organizing

Committee, consisting of representatives from NOAA, Dept. of Int., and the State of Alaska, was formed to review issues raised and the workshop and to plan for further coordination of ecosystem research in the Bering Sea. Topics the organizing committee are discussing include: coordination of field sampling plans, sharing of databases, traditional local knowledge, and the development of a Bering Sea Ecosystem Science Plan.

#### *National Oceanic and Atmospheric Administration- Cooperative Projects*

NOAA has conducted Bering Sea fisheries surveys and research for many years. NOAA managed OCSEAP during the 1970s and 1980s. Recently NOAA has funded several cooperative projects that focus on the Bering Sea ecosystem.

#### Arctic Research Initiative (ARI) (FY98 Funding level \$1,500K)

In 1997 NOAA began the Arctic Research Initiative: Studies on the Health of the Western Arctic/Bering Sea Ecosystem (Cooperative Institute for Arctic Research 1997). ARI's overall goal is to address the following national arctic policy objectives: protecting the arctic environment and conserving its biological resources, assuring that natural resource management and economic development are environmentally sustainable, strengthening institutions for international cooperation, and involving the region's indigenous people in decisions that affect them. Coordinated by the NOAA/University of Alaska Cooperative Institute for Arctic Research (CIFAR), ARI focuses on two research areas. The first, natural variability of the Western Arctic/Bering Sea ecosystem, is concerned with the role of the "green belt" and atmosphere-ice-ocean processes that influence ecosystem variability. The second, anthropogenic influences on the Western Arctic/Bering Sea ecosystem, examines arctic haze, ozone, and UV flux and their impacts, and contaminant inputs, fate, and effects on the ecosystem.

ARI's main scientific issues are:

1. Define and understand the physical, chemical and biological processes that lead to sustained ecosystem production in the "green belt."
2. Understand the atmosphere-ice-ocean processes that create change, especially decadal shifts, in the oceanography and biology of the Bering Sea.
3. Define variability in atmospheric circulation as a driver for arctic haze, ozone and UV flux. Characterize ozone anomalies and loss, and understand the chemical and physical characteristics of arctic haze.
4. Determine pathways/linkages of contaminant accumulation in species that are consumed by top predators, including humans, and use an ecosystems approach to determine the effects of contaminants on food web and biomagnification.

#### Fisheries-Oceanography Coordinated Investigations (Supports NOAA investigator salaries.)

FOCI was established by NOAA in 1986 to examine the physical and biological factors that affect commercial fisheries in Alaskan waters and to provide information to resource management (Schumacher and Kendall 1995). Research is conducted mainly by personnel at two NOAA laboratories in Seattle, Washington: the National Marine Fisheries Service's Alaska Fisheries Science Center (AFSC) and the Office of Oceanic and Atmospheric Research's (OAR's) Pacific Marine Environmental Laboratory (PMEL), with assistance from scientists at several joint NOAA/university institutes, including those at the Universities of Alaska, Washington and Oregon State. Researchers from other academic and research institutes from across the nation have been part of the FOCI effort. The goal of FOCI is to understand the influence of changes in the environment on the abundance of various commercially valuable fish

and shellfish stocks in Alaskan waters and to examine the role of these animals in the ecosystem. Presently, FOCI research focuses on factors influencing recruitment to stocks of pollock, with emphasis on early life stages (egg through young of the year), and their associated ecology. Among FOCI's legacy is the development and implementation of models to integrate biophysical observations, the evolution of technologies to measure biophysical conditions and to access condition factors of larval pollock, and the development of methods to apply research results to fisheries management.

#### Southeast Bering Sea Carrying Capacity (FY98 funding level \$950K)

SEBSCC is a NOAA Coastal Ocean Program Regional Ecosystem Study begun in 1996 that is administered by the University of Alaska, AFSC, and PMEL. SEBSCC followed Bering Sea FOCI, a project that evaluated stock structure of pollock in the Bering Sea and examined their recruitment dynamics. SEBSCC's goal is to increase understanding of the southeastern Bering Sea ecosystem, to document the role of juvenile pollock and factors that affect their survival, and to develop and test annual indices of pre-recruit (age-1) pollock abundance.

SEBSCC scientific questions (NOAA Coastal Ocean Program 1995) address productivity of the region and climatic and anthropogenic effects on the ecosystem:

1. How does climate variability influence the Bering Sea ecosystem? How does climate variability affect the physical regimes of the southeastern Bering Sea? Is there historical evidence for a regime shift in the Bering Sea, and how is this reflected in ecological relationships? What information will we need to further clarify this? How have past changes in the species mix in the region related to climatic and oceanographic variability?
2. What limits population growth in the Bering Sea? Is there evidence of a carrying capacity, e.g., for pollock? What is the role of cannibalism in controlling pollock populations? What is the feeding and switching behavior of juvenile pollock and their predators? What is the ecological role of pollock in the Bering Sea, and what energetic links exist among pollock and apex species?
3. How do oceanographic conditions influence biological distributions? How do oceanic conditions influence overlap or separation between predators and prey? Do ocean conditions create discrete aggregations of pollock, and do life histories differ in separate aggregations? Does sea ice influence the distribution of pollock, and if so, how? What maintains separations between biophysical domains?
4. What influences primary and secondary production regimes? How do primary and secondary production respond to climatic variability? What are the sources of nutrients to the southeastern Bering Sea shelf, and what processes affect their availability?

#### Marine Mammals Protection Act – Bering Sea Ecosystem Study Plan (Not funded)

The 1994 amendments to the MMPA included a provision that the Secretary of Commerce develop a research program to monitor the health and stability of the Bering Sea ecosystem. The research program was to resolve uncertainties concerning the causes of population declines in marine mammals, sea birds, and other living resources of that marine ecosystem. The amendments further required that the program address research recommendations developed by previous workshops on the Bering Sea, and that it include research on subsistence uses of such resources and ways to provide for the continued opportunity for such uses. The Secretary was directed to utilize, where appropriate, traditional local knowledge in the conduct of the research. In early 1995, the National Marine Fisheries Service developed a draft study plan that was

refined at a workshop to discuss habitat, ecosystems, marine mammals, sea birds, and fisheries and trophic interactions (National Marine Fisheries Service 1995).

Important scientific questions identified by the MMPA Bering Sea Ecosystem Study Plan include:

1. Do climate fluctuations affect the transfer of nutrients from the basin to the shelf? What is the impact of those fluctuations to the food chain, marine mammals and seabirds.
2. Climate variability affects the seasonal production and extent of sea ice. How does sea ice affect the top down and bottom up processes that influence seabird and marine mammal demography?
3. What are the effects of commercial fishing activities (such as removal of fish biomass, return of discards and offal to the sea, pulse fishing, trawl exclusion zones, and gear impacts on the bottom) on the ecosystem? In particular, what are the effects on those components that are trophically linked to the targeted populations?
4. Is the effect of contaminants (heavy metals, organics, and offal) limited to the proximity of contaminated sites/ sources or can it be traced through the ecosystem via biological and physical pathways?
5. Climate variability influences the basic circulation and heat content of the Bering Sea. How would major perturbations or secular trends in circulation, vertical structure, and heat content affect habitat quality for Bering Sea marine mammals and seabirds.

#### NOAA's Bering Sea Ecosystem Management Project (BSEMP) (FY99 funding level \$125K)

The Office of the Governor for the State of Alaska, Division of Governmental Coordination and the St. Paul Coastal district received funding from NOAA for FY98 for this project. Its overall purpose is to increase coordination and communication among those interested in Bering Sea ecosystem management. The project proposes to promote interagency cooperation, investigate the feasibility of developing an ocean management plan for the Bering Sea, and develop annotated bibliographies about ecosystem management and local knowledge.

#### *Interorganizational Projects*

##### Seabird, Marine Mammal and Oceanography Coordinated Investigations (SMMOCI)

Forage fishes comprise the primary prey base for several species of marine birds and mammals that have been monitored in Alaska over the past 20 years. Knowledge of the marine ecosystem is important for understanding causes of changes. Four organizations (U.S. Fish and Wildlife Service, National Marine Fisheries Service, U.S. Geological Survey, and University of Alaska Fairbanks) have agreed to cooperate in an effort to characterize foraging habitat for seabirds and Steller sea lions at six locations in the Gulf of Alaska and Bering Sea where background monitoring data are available. We began the nearshore marine habitat characterization in 1995 at Unimak Pass in the eastern Aleutian Islands where seabirds and sea lions have been monitored on two nearby islands: Aiktak and Ugamak. Hydroacoustic data were collected along a series of transects within a 50-km radius of the islands to describe the distribution and biomass of potential prey. Midwater and bottom trawls were conducted to support the hydroacoustic surveys, and longline sets were made to help characterize the bottom fish fauna. Marine bird and mammal observations were made during all daylight transects, and adult seabirds were collected to characterize diet composition. Preliminary results suggest such studies can

adequately describe ecosystem components and may ultimately help reveal patterns that demonstrate the response of top-level predators to fluctuations in the prey base.

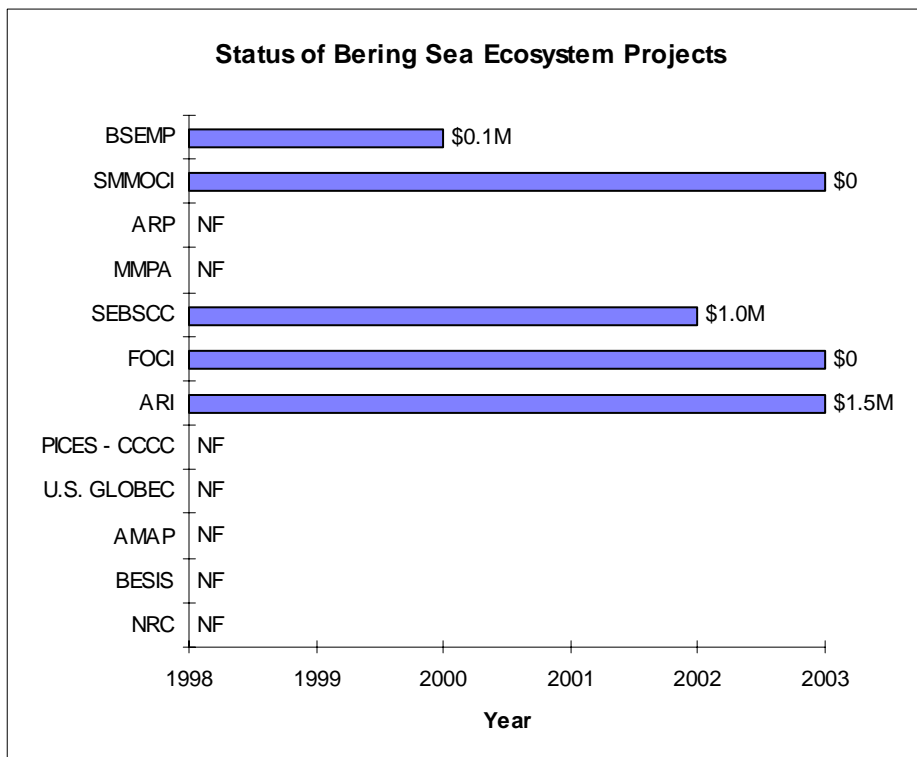


### Presently funded cooperative programs

Although many research plans have been developed for the Bering Sea, very few cooperative programs have actually been funded (Appendix Table 1, Appendix Figure 1).

Appendix Table 1.— Bering Sea ecosystem-related plans or projects and research foci.

<b>Plan or Project Name</b>	<b>Research Focus</b>
NRC - National Research Council Report on the Bering Sea	Ecosystem dynamics - climate and human-induced change
BESIS - Bering Sea Impacts Study	Regional impacts of global change - from climate to all trophic levels
AMAP	Amount and effects of pollutants
U.S. GLOBEC	Effects of climate variability on marine animals
PICES Bering Sea Working Group and Climate Change and Carrying Capacity Program	Effects of climate variability and fishing on ecosystems
ARI - NOAA - Arctic Research Initiative	Natural variability of the ecosystem and contaminant inputs, fate, and effects. Themes include: Green belt biology, air-ice-ocean interactions, Boundary layer, arctic haze and UVB, and contaminants
FOCI - NOAA- Fisheries Oceanography Coordinated Investigations	Physical and biological factors affecting commercial fisheries
SEBSCC - NOAA-Southeast Bering Sea Carrying Capacity	Effects of climate variability on the ecosystem - FY99-00 emphases: availability of nutrients on the Bering Sea shelf and relation of juvenile walleye pollock to top predators
MMPA - Bering Sea Ecosystem Study Plan	Monitor the health and stability of the Bering Sea ecosystem - marine mammal and seabird emphasis
ARP - Alaska Regional Marine Research Program - Alaska Research Plan	Safeguarding water quality and ecosystem health - effects of natural and human factors
SMMOCI - Seabird , Marine Mammal and Oceanography Coordinated Investigations	Characterize foraging habitat for seabirds and Steller sea lions at specific locations in the Gulf of Alaska and Bering Sea to understand the response of top-level predators to fluctuations in prey base
BSEMP - NOAA Bering Sea Ecosystem Management Project	Increase coordination and communication among those interested in Bering Sea ecosystem management.



Appendix Figure 1. Funding status and timeline for various Bering Sea cooperative programs. (NF = not funded).

There are four programs that presently support cooperative research in the Bering Sea. Two of the programs (FOCI and SMMOCI) are not fully funded with base agency funds. At present, FOCI investigators in NOAA have support for salary but not for shiptime and other resources needed to carry out research. Salary support is part of NOAA base funding and should continue into the future. SMMOCI investigators bring their own resources from their respective organizations to carry out the research so the program is not officially funded. The other two funded programs have limited funding horizons. NOAA's Arctic Research Initiative will be funding projects through FY99. This program has been funded as a congressional add-on in previous years and funding status beyond FY99 is very uncertain. The funding for NOAA's Southeast Bering Sea Carrying Capacity Program will be around \$1,000K through FY00 and will then be phased out in the final two years of the program (FY01-02) with funding levels of \$700K and \$292K, respectively. NOAA's BSEMP project will be funded for FY99 at \$125K and funding level for FY00 is presently unknown.

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